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Canadian Atlantic Fisheries
Scientific Advisory Committee

CAFSAC Res. Doc. 81/57

# Assessment of snow crab (Chionoecetes opilio) stocks in Newfoundland, 1979

by

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## ABSTRACT

Population size estimates for snow crab (Chionoecetes opilio) off the east coast of Newfoundland, based on Peterson mark-recapture and Leslie analyses, are presented. Within given crab management areas, estimates of population size ranged from 716 to 21,473 MT and exploitation rates from 34 to 74%.

## RESUME

L'article qui suit contient des estimations d'effectifs des populations de crabes des neiges (Chionoecetes opilio) au large de la côte est de Terre-Neuve. Ces estimations sont fondées sur la méthodes des marques-recaptures de Peterson et sur des analyses de Leslie. A l'intérieur des différentes zone de gestion de cette espèce, les estimations de l'importance des populations sont comprises entre 716 et 21 473 tm, et les taux d'exploitation entre 34 et 74%.

## INTRODUCTION

The Newfoundland snow crab (Chionoecetes opilio) fishery began in 1968. Landings initially consisted solely of animals obtained as by-catch from the groundfish gillnet fishery. Initial demand for snow crab was encouraging, inducing fishermen to begin fishing this species exclusively. With the exception of the 1975-76 season when markets were quite poor, landings have steadily increased to a high of 11,000 metric tons in 1979. In 1980, the inshore fishery dispute and poor market conditions caused a cessation in fishing activity of five to eight weeks duration. Despite this interruption, landings for 1980 are expected to exceed 9500 MT.

Fifty-one vessels are engaged in the fishery and range in length from 40 to 65 ft. Most vessels are capable of landing far greater amounts of snow crab than plant imposed quotas permit. Therefore, landings in Newfoundland are largely a reflection of market conditions and processing capacity.

"Japanese-style" conical traps are used exclusively in the Newfoundland fishery. Traps are baited with frozen squid and set in longline fleets of 35-75 traps attached at 15-20 fm intervals. Soak time of gear will vary due to many factors but is generally of 24-48 hr. duration.

In Newfoundland, as in the Maritime Provinces and Quebec, the fishery is restricted to male snow crab having a minimum carapace width of 95 mm. This ensures that there will be sufficient sexually mature males on the grounds to maintain snow crab populations (Watson 1970). The only seasonal restrictions on the Newfoundland fishery is that fishing is prohibited during the month of January. Traditionally, the fishery is conducted from April until November. In CAFSAC Advisory Document 81/1 (CAFSAC, 1981) it has been recommended that exploitation rates on various populations not exceed 50-60%.

Although a commercial snow crab fishery has been ongoing in Newfoundland since 1968 very little effort has been expended in stock management. The Leslie analyses and Petersen models presented herein represent a first attempt to assess Newfoundland snow crab stocks.

## MATERIALS AND METHODS

Information on fishing effort and catch per unit of effort (CPUE) prior to 1979 could not be obtained from log books since only a very few fishermen maintained them. In an attempt to obtain representative data, as many fishermen as possible were interviewed either in person or by telephone. Each was asked where he fished, approximately how many traps were hauled per day and how many traps per fleet were used. Sales slips for each year were then obtained from the Economics and Intelligence Branch of the Department of Fisheries and Oceans and CPUE for each fisherman calculated.

In 1979, a mandatory log book was issued to all licensed crab fishermen. The data obtained from the returned log books included, number of traps hauled per day, catch per day, and fishing position. From these data CPUE and cumulative catch were calculated for each management area. Daily catch figures from log books were checked against processor's sales slips to ensure the accuracy of

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the data. CPUE and cumulative catch data were used to perform Leslie analyses for each management area (Fig. 1). This methodology has been used previously by Bailey (1978 a and b) and Elner and Robichaud (1980).

During the summer of 1979 a tagging program was begun in 3 management areas, 18, 24 and 26. Information from tag returns was used to generate biomass estimates using Petersen's method (Ricker 1975) and to gain insight into snow crab movements in these areas.

Crabs were captured using standard Japanese-style conical traps baited with squid and set in longline fleets of 8. Traps were fished for approximately 24 hr before hauling. Animals were removed from the traps immediately after hauling, measured (maximum carapace width) to the nearest mm with vernier calipers and classified by shell condition. Hard-shelled, legal sized animals were tagged using a Floy vinyl "spaghetti" tag tied around the body and returned to the fishing grounds. Tags from recaptured animals were obtained from fishermen either personally or by mail.

## RESULTS AND DISCUSSION

Areas currently fished in Newfoundland are divided into two zones at the line separating management areas 26 and 28 (Fig. 1). Although vessels licensed to fish either zone are permitted to fish in the other, historically this has rarely occurred. Vessels in the southern zone (Areas 2-26) are generally larger than those in the northern zone and tend to fish crab exclusively, while many northern zone vessels harvest a number of species. Also, southern zone vessels fish more traps per day and venture farther offshore than do those in the northern zone.

The mandatory log book regulation worked extremely well. Approximately 95% of the fishermen maintained good records in their log books. However, fluctuations in weekly effort due to weather conditions caused gaps in the data which made Leslie analyses based on weekly CPUE difficult. Therefore, effort and landings data for most areas were combined into 2 week periods to facilitate analyses by providing estimates of representative effort data where gaps had previously existed.

The Leslie analyses for Newfoundland snow crab management are as follows.

### Southern Zone

#### Bonavista Bay - Areas 26 and 24

Although examination of Figure 2 would seem to indicate that most crabs are found in one large area, vessels from area 24 and 26 do not occupy the same grounds. In fact, vessels from the respective areas rarely come within visual range of each other. Therefore, there are two distinct fisheries in Bonavista Bay. Also, in mid-season CPUE in area 24 was so low that vessels left that area and began fishing in Trinity Bay (Table 2). If Bonavista Bay were to be assessed as one management area the great decrease in CPUE in area 24 would be masked by the comparatively high catch rate in area 26. For these reasons, assessments for the two areas have been done independently.

Area 26 - western Bonavista Bay

Historical data on landings (MT), mean CPUE (kg/trap haul) and effort (trap hauls) are summarized below.

| | 1973* | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | - | 105 | - | 300 | 490 | 676 | 744 |
| CPUE | - | - | - | 7.7 | 11.3 | 14.5 | 10.9 |
| Effort | - | - | - | 38,875 | 43,254 | 46,599 | 67,690 |

* data on effort prior to 1973 are not available

The total biomass available (B) in area 26 as calculated by Leslie analysis (Fig. 3) was 1003 MT with 95% confidence limits of 822 MT and 1396 MT; $r^2 = 0.81$. The exploitation rate for this area was 74% in 1979.

The commercial biomass available in area 26 before the fishery began, assuming that catchability (q) is constant (Table 1) is calculated as:

$$\frac{CPUE}{q}_t = B_t$$

$$= \frac{13.5}{1.707 \times 10^{-5}}$$

$$= 791 \text{ MT}$$

Therefore, 212 MT were added to this initial biomass through growth and recruitment during the fishing season. The effort expended during the first week of the fishery was not representative of the level of effort for most of the season and data for this period were not used. The landings for this period, 7 MT, were added to the calculation of initial biomass which becomes 798 MT.

The above table clearly illustrates that while effort in 1979 increased by 45%, CPUE was lower than the 1978 level. This fact plus the high exploitation rate for this area (74%) would indicate that there is too much fishing effort in this area. However, events which transpired in 1980 have changed the outlook for area 26. In 1980, the vessel which expends the greatest effort in the area began fishing a previously unexploited area east of Cabot Island (Fig. 2). The effort directed at the traditional fishing areas was greatly reduced. In view of this development, the authors feel that despite the fact that the recommended exploitation rate was exceeded, reducing the effort for area 26 is not recommended. In fact depending on how productive the new grounds prove to be, it is possible that this area could support additional fishing effort.

Area 24 - Eastern Bonavista Bay

Historical data on landings (MT), mean CPUE (kg/trap haul) and effort (trap hauls) are summarized below.

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | - | 11 | 40 | 370 | 567 | 1,077 | 842 |
| CPUE | - | 4.1 | 5.9 | 7.7 | 10.4 | 12.7 | 8.4 |
| Effort | - | 2,724 | 6,851 | 47,941 | 54,369 | 84,804 | 105,615 |

The total available biomass (B) for area 24 as estimated by Leslie analysis (Fig. 4) was 1208 MT with 95% confidence levels of 1029 MT and 1530 MT; $r^2 = 0.96$. The exploitation rate for this area was 70%. The initial available biomass for this area (Table 2) is calculated as:

$$\frac{CPUE_t}{q} = B_t$$

$$= \frac{12.2}{1.192 \times 10^{-5}}$$

$$= 1024 \text{ MT}$$

Therefore, 184 MT were added to the initial biomass through growth and recruitment during the fishing season.

The estimated 70% exploitation rate in this area for 1979 is in excess of the exploitation rate recommended in CAFSAC Advisory Document 81/1 (CAFSAC 1981). In 1980 the low CPUE continued and resulted in an even earlier move by fishermen to Trinity Bay.

Tagging Study 1979 - Areas 24 and 26

During the spring of 1979 a total of 3160 hard-shelled snow crab were tagged with a vinyl body tag and released on the commercial crab grounds; 1531 on the eastern side of the bay and 1629 on the western side.

A letter explaining the tagging program and its purpose was sent to each licensed snow crab fisherman along with a "Reward" poster which illustrated the position of the tag on the crab's body and detailed what information was required. Recaptured tags were either mailed to our office or obtained directly by personnel working in the field. A total of 1470 tags was returned; 686 from the eastern side of the bay and 784 from the western side.

The data generated as a result of this study were used to perform a Petersen's estimate of usable biomass:

$$B = \frac{(M)\ (n)}{m} \qquad (1)$$

where

M = the number of marked animals released from the first sample (number tagged)

n = the numbers of animals examined for marks in the second sample (total catch of crab after release of tagged animals)

m = the number of marked animals in the second sample (number of tagged crabs caught)

The approximate 95% confidence limits for these estimates for $m > 50$ are $m + 1.92 \pm 1.96 \sqrt{m + 1}$, Ricker (1975). Solved for m, the value is re-entered into equation (1).

In 1979, the commercial fishery commenced before the tagging program was implemented, therefore, the amount of snow crab caught before tagging is subtracted from the total catch in each area to provide a true value for B.

The snow crab population on the western side of Bonavista Bay is therefore given by:

$$B = \frac{(M)\ (n)}{m}$$

$$= \frac{(1629)\ (441{,}844^*)}{784}$$

$$= 918{,}066 \text{ kg } (918 \text{ MT})$$

with 95% confidence limits of 856 MT and 985 MT. Therefore initial biomass = 918,066 + 295,079 = 1,213,145 kg (1213 MT).

In Area 24 tagging was also delayed until well after fishing activity had begun. Landings after tagging had commenced reached 595,299 kg (595 MT).

The snow crab population in the eastern side of Bonavista Bay is therefore given by:

$$B = \frac{(M)\ (n)}{m}$$

$$= \frac{(1531)\ (595{,}299)}{686}$$

$$= 1{,}328{,}575 \text{ kg } (1329 \text{ MT})$$

with 95% confidence limits of 1233 MT and 1432 MT. Thus initial biomass available = 1,328,575 + 246,923 = 1,575,498 kg (1576 MT).

* average weight of a legal-sized snow crab is 0.45 kg.

Area 22 Trinity Bay (outer portion)

This area situated at the mouth of Trinity Bay is fished exclusively by vessels from area 24. 1979 was the first year that the fishery in this area was prosecuted.

Leslie analyses of the log book data for this area (Fig. 5) provides a total usable biomass estimate (B) of 1467 MT with 95% confidence limits of 1011 MT and 3233 MT; $r^2 = 0.74$. The exploitation rate for this area was 39%.

The initial biomass available in the area (Table 3) is calculated as:

$$\frac{CPUE_t}{q} = B_t$$

$$= \frac{12.5}{8.650 \times 10^{-6}}$$

$$= 1445 \text{ MT}$$

This calculation of initial biomass indicates that there was no appreciable increase in the population through growth and recruitment during the fishing season. This is what one would expect of a virgin population. This rate of exploitation is very near the 40% level that CAFSAC recommended as the maximum rate for virgin populations. Sampling data and ancedotal evidence from fishermen in 1980 indicate that already, catch rates have dropped significantly, mean size of animals has decreased while the incidence of soft-shelled animals has increased.

Area 20 - Trinity Bay (Inner Portion)

This area (Fig. 1) is fished by two vessels on a sporadic basis. Log book data were insufficient for Leslie analysis. Historically, this area has been fished since 1969 but since the early 1970's, has not supported a fishery of any consequence.

The historical data on landings (MT), mean CPUE (kg/trap haul) and effort (trap hauls) are summarized below.

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | 48 | 31 | 16 | 45 | 63 | 56 | 67 |
| CPUE | 14.5 | 11.3 | 10.4 | 11.3 | 9.5 | 17.2 | 16.0 |
| Effort | 3,305 | 2,716 | 1,494 | 3,926 | 6,647 | 3,249 | 4,165 |

Although CPUE for this area is commercially acceptable, snow crab distribution is patchy making fishing this population unattractive to most fishermen. It is anticipated that effort in this area will continue at a very low level.

Area 16 - Conception Bay

The snow crab fishery began in this area in 1970. During the early 1970's this area was quite productive and, until CPUE became quite low in 1975-76, was the mainstay of the fishery. Recently, the CPUE in this area has risen to acceptable commercal levels (Table 4) and there has been a significant increase in the level of effort in the Bay (see text table). Fishermen exploiting this population also fish in area 18 (Fig. 1).

The historical data on landings (MT), mean CPUE (kg/trap haul) and effort (trap hauls) are summarized below.

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | 779 | 235 | 46 | 56 | 174 | 81 | 464 |
| CPUE | - | 6.8 | 5.0 | 9.1 | 8.6 | 10.9 | 16.1 |
| Effort | - | 34,492 | 9,152 | 6,205 | 20,171 | 7,414 | 28,845 |

Leslie analysis of the log book data for this area (Fig. 6) provides an estimate of total usable biomass (B) of 1351 MT with 95% confidence limits of 951 MT and 3204 MT; $r^2 = 0.70$. The exploitation rate for this area in 1979 was 34%. Preliminary indications for the 1980 season are that effort and landings in this area were sharply increased. This was principally due to the poor market conditions which forced most processors to place severe catch quotas on all vessels. This quota reduction (often by as much as 1/3) made fishing in the more distant area 18 uneconomical for many vessels and therefore much of their effort was transferred to area 16. Initial biomass available (Table 4) is as follows:

$$\frac{CPUE_t}{q} = B_t$$

$$= \frac{16.8}{1.519 \times 10^{-5}}$$

$$= 1106 \text{ MT}$$

Area 18 - Northeastern Avalon

Since the early 1970's, this area has been the mainstay of the fishery accounting for more than ½ of the reported landings for the island. Fishing is conducted over a large area, from 2 to 64 km offshore. Vessels fishing this area tend to be larger than those in the other areas and have a much greater catching capacity than is indicated by their daily landings. A total of 24 vessels presently fish this area.

The historical data on landings (MT), mean CPUE (kg/trap haul) and effort (trap hauls) are summarized below.

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | 805 | 473 | 181 | 444 | 1,480 | 3,646 | 6,870 |
| CPUE | 15.9 | 6.4 | 6.4 | 10.4 | 13.2 | 13.6 | 17.2 |
| Effort | 50,736 | 74,428 | 28,442 | 42,596 | 112,522 | 267,933 | 398,939 |

Two vessels in this area fished traps much larger than standard size. This caused these vessels to have a much higher CPUE than others, particularly when crab were very abundant. For this reason data for these vessels are not included in Table 5 and were not used in performing Leslie analyses.

Leslie analysis of log book data (Fig. 7) provides a usable biomass estimate (B) of 14,359 MT, with 95% confidence limits of 11,778 MT and 19,792 MT; $r^2 = 0.82$. The exploitation rate for this stock was 44%.

It should be noted that a large proportion of these 1979 landings are taken from virgin grounds and a reduction in CPUE will probably occur in the future.

Initial biomass available (Table 5) is calculated as:

$$\frac{CPUE_t}{q} = B_t$$

$$= \frac{21.5}{1.808 \times 10^{-6}}$$

$$= 11{,}891 \text{ MT}$$

Thus 2458 MT were added to the initial biomass through growth and recruitment during the fishing season. Much of this additional biomass is probably from the near shore areas which have been commercially fished since the early 1970's.

Petersen's estimate.

A total of 3155 snow crab were tagged and released at 22 tagging sites over a large portion of area 18. The procedure used was identical to that followed in the Bonavista Bay tagging studies. A total of 1001 tags was recovered. Data generated from this study were used to calculate available biomass using Petersen's method.

$$B = \frac{(M)\ (n)}{m} \qquad (1)$$

In 1979, the fishery commenced before the tagging program was implemented. Therefore, the landings for the period prior to tagging (84,143 kg) must be subtracted from the total landings to provide n.

Therefore the snow crab population for area 18 is:

$$\frac{(3155)\ (6,786,117)}{1001}$$

$$= \quad 21,389 \text{ MT}$$

Approximate 95% confidence limits are 20,144 MT and 22,756 MT.

Initial available biomass = 21,389+84=21,473 MT.

Area 14 - Eastern Avalon

This area has supported a fishery since 1977. Three vessels fish this area, however, only two of them expend significant fishing effort. The historical data on landings (MT), CPUE (kg/trap haul) and effort (trap hauls) are summarized below.

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | 49 | 366 | 659 | 655 | 167 | 824 | 762 |
| CPUE | - | 8.2 | 9.1 | 11.3 | 9.9 | 15.9 | 20.1 |
| Effort | - | 44,840 | 72,589 | 57,718 | 16,761 | 51,888 | 37,950 |

Leslie analysis of the log books from this area (Fig. 8) provides a usable biomass estimate (B) of 1095 MT, with 95% confidence limits of 891 MT and 1681 MT; $r^2 = 0.80$. The exploitation rate in this area was estimated at 70% which is well above that recommended by CAFSAC (50-60%).

The initial biomass available for this area (Table 6) is estimated as:

$$\frac{CPUE_t}{q} = Bt$$

$$= \quad \frac{22.6}{3.336 \times 10^{-5}}$$

$$= \quad 678 \text{ MT}$$

However, landings for the period of April 2-15 (38 MT) were omitted from this calculation. Therefore, initial biomass is 678 + 38 = 716 MT. Therefore, 379 MT were added to the initial available biomass through growth and recruitment during the fishing season.

It is noteworthy that despite the high exploitation rate in this area CPUE remained comparatively high (Table 6).

Area 12 - South Eastern Avalon Peninsula

Due to the higher catch rates in areas 14 and 18, fishing effort in this area has been negligible since 1978.

Historical data on landings (MT) mean CPUE (kg/trap haul) and effort (trap hauls) are summarized below:

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | 547 | 749 | 337 | 212 | 457 | 276 | - |
| CPUE | - | 13.6 | 8.6 | 16.8 | 14.9 | 14.1 | - |
| Effort | - | 55,045 | 39,153 | 12,643 | 30,562 | 19,643 | - |

Preliminary data for 1980 indicate that catch rates in areas 14 and 18 were slightly reduced over 1979 levels. Should this trend continue, it is probable that effort would shift back to area 12.

Northern Zone

Area 36 - White Bay

White Bay, situated on the northeast coast of the island (Fig. 1), is a deep narrow bay. The fishery in this area began in 1973. Although effort is low, CPUE is also quite low. This is probably due to the fact the crab grounds are quite small in area being restricted to the near shore areas. A total of five vessels are engaged in the fishery in this area.

The historical data on landings (MT), mean CPUE (kg/trap haul) and effort (trap hauls) for this area are summarized below.

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | 62 | - | 45 | 48 | 52 | 169 | 156 |
| CPUE | - | - | - | - | 16.3 | - | 7.3 |
| Effort | - | - | - | - | 3,210 | - | 21,298 |

Leslie analysis of log book data (Fig. 9) provides a total usable biomass estimate (B) of 383 MT, with 95% confidence limits of 265 MT and 887 MT; $r^2 = 0.72$ while the exploitation rate in this area is 41%.

It must be noted that because effort from September 17 to October 30 was minimal, data from this period were not used in Leslie analysis (Table 7).

Initial available biomass is calculated as:

$$\frac{CPUE_t}{q} = B_t$$

$$= \frac{9.6}{2.486 \times 10^{-5}}$$

$$= 386 \text{ MT}$$

Area 34 - Horse Islands

During 1979 this area was sporadically fished by one vessel. The data were insufficient to estimate available biomass and exploitation rate for 1979.

The historical data on landings (MT), mean CPUE (kg/trap haul) and effort (trap hauls) are summarized below.

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | - | 46 | 347 | 92 | 62 | 98 | 141 |
| CPUE | - | - | - | - | 9.1 | - | 11.9 |
| Effort | - | - | - | - | 6,842 | - | 11,830 |

Area 32 - Green Bay

The fishery in Green Bay is primarily prosecuted from Little Bay Islands. Fishing is conducted at depths ranging from 256 to 476 m. The fishery began in 1972 and at present six vessels are engaged in it. Fishing areas have a patchy distribution which probably explains why Table 8 indicates that there is no growth or recruitment during the fishing season. If growth and recruitment did occur during the fishing season, quality control on the part of fishermen and the processor would ensure that soft-shelled animals were not represented in landing statistics.

The historical data on landings (MT) mean CPUE (kg/trap haul) and effort (trap hauls) are summarized below.

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|
| Landings | 83 | 49 | 117 | 173 | 232 | 340 | 491 |
| CPUE | - | - | - | - | 6.4 | 8.7 | 10.6 |
| Effort | - | - | - | - | 36,477 | 39,008 | 46,183 |

Leslie analysis of log book data (Fig. 10) gives a total usable biomass estimate (B) of 882 MT, with 95% confidence limits of 76 MT and 1077 MT; $r^2 = 0.88$ while the exploitation rate in this area is 56%. Initial biomass

for this area (Table 8) is as follows:

$$\frac{CPUE_t}{q} = B_t$$

$$= \frac{15.6}{1.829 \times 10^{-5}}$$

$$= 853 \text{ MT}$$

Reliability of Leslie Analysis

The biomass estimates obtained from Leslie analysis are reliable provided that certain assumptions are upheld. These are: (1) catchability of the animal remains constant; (2) the population is totally available to the fishery; (3) there is no natural mortality or recruitment during the fishing season; and (4) the fishing effort applied is constant throughout the season (Lackey and Hubert 1977). Given the nature of the fishery, none of the above conditions can be met absolutely.

It is doubtful that the catchability of snow crab remains constant throughout the fishing season. In Newfoundland the season is quite lengthy, lasting from May until December. During this time there are great fluctuations in food availability which would certainly affect catchability. The fact that most crabs moult during this time period would also affect catchability.

It is also unlikely that all animals are totally available to the fishery. The physiological rigors of moulting would make crab unavailable for trapping for at least part of the fishing season. Also, fishermen in Newfoundland rarely fish in depths less than 183 m (100 fathoms). However, research cruises carried out by the authors resulted in significant catches of crab in shallower waters. Obviously, a portion of the biomass is not available to the fishery and Leslie analyses would not take these animals into account.

Doubtless, there is some natural mortality in the snow crab population in Bonavista Bay, however, it is probably negligable in crab of legal size. Predators would not account for any significant mortality, while in commercially exploited areas "old age" mortality would certainly be insignificant. Due to these factors, natural mortality has not been considered as significantly affecting biomass estimates and has therefore not been calculated. Although growth of legal sized animals and moulting of undersized animals to legal size occurs during the fishing season, strict quality control on the part of fishermen and processing plants ensures that very few of these soft-shelled animals are retained. This however, poses a difficulty when assessing snow crab biomass in that the figure derived for the biomass of commercial-sized snow crab left on the grounds is underestimated. In view of the restraint exercised by fishermen in landing soft-shelled crab it is probable that biomass estimates of remaining stock for most areas are underestimated.

To determine the degree of recruitment and growth occurring in a population sufficient data must be obtained by at-sea sampling on commercial vessels or research vessels. Although several research cruises were made to commercial

crab grounds during 1979 they did not coincide with the seasonal peaks in moulting activity.

Due to weather conditions and processors catch quotas, fishing effort on either side of the bay is rarely constant. However, for the season as a whole, fishing effort is constant enough not to be an anomalous factor in determining snow crab biomass (see Tables).

Reliability of Petersen's Estimate

In order that a Petersen's estimate be accepted as a reliable population estimator certain criteria have to be met. These are discussed in Seber (1973), Ricff (1973) and Bowen (1979). They are:

1. The population is closed so that N is constant,
2. Animals do not lose their marks in the time between the two samples,
3. Marking does not affect the catchability of the animals,
4. Marked animals are randomly distributed throughout the population in the second sample,
5. All animals have the same probability of being caught in the first sample,
6. Sampled animals are correctly classified as marked or unmarked, and
7. All marks are reported on recovery in the second sample.

These assumptions and whether they are met in this study will be discussed individually.

1. N is constant. Due to the habitat and comparatively large size of this population, this assumption cannot be tested. The fact that moulting occurs during the fishing season would indicate that N varies a great deal during the duration of the fishery.

2. Animals do not lose their marks in the time between the two samples. Because moulting occurs during the fishing season a system of double tagging such as that used in lobster studies (e.g. banding claws) would be impractical. Possibly, animals could be tagged using a Floy "T-bar" tag. However, due to the high incidence of moulting during the fishing season, we must for the present assume that some animals do lose their tags during this time.

3. Marking does not affect the catchability of the animal. Although this assumption has not been tested we assume that the animals' catchability is not affected. This is due to the fact the fishery is a baited trap fishery in which the fishermen cannot select individual animals.

4. Marked animals are randomly distributed throughout the population in the second sample. This is a difficult assumption to validate. Snow crab distribution in many areas is patchy so one is restricted as to where tagging is feasible. Also, the fishing season was well under way in the area at the time of tagging, severely restricting the grounds available. Within this context, an attempt was made to fish randomly. However, it should be noted that this assumption was not tested.

5. All animals have the same probability of being caught in the first sample. All animals tagged were $\geq$ 95 mm carapace width, had both claws intact and therefore should have had equal access to the pots.

6. Sampled animals are correctly classified as marked or unmarked. This assumption was not tested. However, since the tags are brightly colored and are individually handled twice (once on the vessel and once on the butchering line in the processing plant), the authors feel that all tags are found after recapture.

7. All marks are reported on recovery in the second sample. Although Bowen (1979) tested this assumption the nature of the Newfoundland crab fishery makes this task unnecessary. There are only 38 licensed vessels in the tagging area, the captains of which are known personally by the authors. Also, by means of reward posters, letters to fishermen adn radio broadcasts, the tagging program was well publicized and what to do with recaptured tags made abundantly clear. Therefore, the authors feel that assumption #7 is valid.

In order to ensure that B is unbiased one other factor must be considered Chapman (1951) states that B is unbiased only if $M + b \geq B$. Obviously, when dealing with a population of animals such as snow crab which number in the millions of individuals, this criterion cannot be met. Robson and Reiger (1964: 217) state that in order for a Petersen estimate to be relatively unbiased"...(Mn) must exceed 4 times the (estimated) population size B." Bowen (1979) also deals with this problem. On the western side of Bonavista Bay Mn = (1629) (974,090). Population size as determined by Leslie analyses is 2,210,917 animals. Thus Mn = 718 N and bias is negligible. On the eastern side of Bonavista Bay Mn = (1531) (1,312,397). Population size as determined by Leslie analyses is 2,663,351. Mn = 754N allowing us to conclude that bias is negligible.

In area 18, Mn = 1495N, therefore in this area also, bias is negligible.

The biology of snow crab and the regulations presently in effect do much to ensure that there is little danger of overfishing in the biological sense. Male snow crab become sexually mature well below the minimum legal size (Watson 1970) while females, becuase of their small size do not enter the fishery. Therefore, the authors feel that a snow crab population should be able to support a fisherying operating on a higher exploitation rate than is acceptable in other fisheries. At present, CAFSAC recommends an exploitation of 50-60%. However, it must be noted that because the catching capacity of the fishing fleet is so great (and is increasing yearly), extreme caution must be used in managing the fishery if its economic viability in terms of CPUE is to be maintained.

The authors feel that because so many assumptions of the Petersen estimator have not been met the reliability of estimates obtained by this method are highly questionable. Therefore population estimates derived from Leslie analyses are viewed as being more reliable at this time.

## ACKNOWLEDGMENTS

Appreciation is expressed to Dr W. D. Bowen for his helpful suggestions, P. W. Collins for assistance in statistical analysis, the captain and crew of the M.V. SHAMOOK and Mr Ted Lewis for their assistance in carrying out the crab tagging experiments.

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Table 1. Catch and effort statistics for the snow crab fishery in western Bonavista Bay, Newfoundland, 1979. (Management Area 26)

| Week period | Effort (Trap hauls) | Cumulative effort | CPUE kg/trap haul | Catch M.T. | Cumulative catch M.T. | Estimated biomass (CPUE/q) M.T. |
|---|---|---|---|---|---|---|
| May 7-12 | 490 | 490 | 14.1 | 7 | 7 | 826 |
| May 14-26 | 6,088 | 6,578 | 13.5 | 82 | 89* | 791 |
| May 28-June 9 | 6,295 | 12,873 | 15.3 | 96 | 186* | 896 |
| June 11-23 | 6,385 | 19,258 | 13.5 | 86 | 272* | 791 |
| June 25-July 7 | 6,160 | 25,418 | 12.6 | 77 | 349* | 738 |
| July 9-21 | 5,727 | 31,145 | 10.3 | 59 | 408* | 603 |
| July 23-Aug. 4 | 5,770 | 36,915 | 9.3 | 53 | 461* | 545 |
| Aug. 6-18 | 4,163 | 41,078 | 8.6 | 36 | 497* | 504 |
| Aug. 20-Sept. 1 | 4,924 | 46,002 | 6.8 | 34 | 530* | 398 |
| Sept. 3-15 | 3,897 | 49,899 | 7.5 | 29 | 560* | 439 |
| Sept. 17-29 | 4,962 | 54,861 | 9.6 | 48 | 607 | 562 |
| Oct. 1-13 | 5,075 | 59,936 | 9.1 | 46 | 654 | 533 |
| Oct. 15-27 | 4,300 | 64,236 | 5.9 | 43 | 696 | 346 |
| Oct. 29-Nov. 11 | 2,041 | 66,277 | 13.9 | 28 | 725 | 814 |
| Nov. 12-24 | 1,413 | 67,690 | 13.5 | 19 | 744 | 791 |

$\bar{x}$ CPUE = 11.0 kg/trap haul

* cumulative catches used in Leslie analysis

Table 2. Catch and effort statistics for the snow crab fishery in eastern Bonavista Bay, Newfoundland, 1979. (Management area 24).

| Two-Week period | Effort (Trap hauls) | Cumulative effort | CPUE kg/trap haul | Catch M.T. | Cumulative catch M.T. | Estimated biomass (CPUE/q) M.T. |
|---|---|---|---|---|---|---|
| May 14-26 | 9,552 | 9,552 | 12.2 | 116 | 116* | 1,024 |
| May 28-June 9 | 12,985 | 22,537 | 11.6 | 151 | 267* | 973 |
| June 11-23 | 16,141 | 38,678 | 9.3 | 150 | 418* | 780 |
| June 25-July 7 | 15,241 | 53,919 | 8.5 | 129 | 547* | 713 |
| July 9-21 | 20,702 | 74,621 | 6.4 | 132 | 679* | 537 |
| July 23-Aug. 4 | 20,574 | 95,195 | 4.3 | 89 | 768* | 361 |
| Aug. 6-18 | 5,940 | 101,135 | 5.6 | 33 | 801 | 470 |
| Aug. 20-Sept. 1 | 1,930 | 103,065 | 8.5 | 16 | 817 | 713 |
| Sept. 3-15 | 50 | 103,115 | 6.8 | 0.3 | 817 | 571 |
| Sept. 17-29 | - | - | - | - | - | - |
| Oct. 1-13 | 100 | 103,215 | 2.8 | 0.3 | 818 | 235 |
| Oct. 15-27 | 1,200 | 104,415 | 9.3 | 11 | 828 | 780 |
| Oct. 29-Nov. 10 | 750 | 105,165 | 10.8 | 8 | 837 | 906 |
| Nov. 12-24 | 450 | 105,615 | 12.6 | 6 | 842 | 1,057 |

$\bar{X}$ CPUE = 8.4 kg/trap haul
* cumulative catches used in Leslie analysis

Table 3. Catch and effort statistics for the snow crab fishery in Trinity Bay (Area 22), Newfoundland, 1979.

| Week period | Effort (trap hauls) | Cumulative effort | CPUE kg/trap haul | Catch M.T. | Cumulative catch M.T. | Estimated biomass (CPUE/q) M.T. |
|---|---|---|---|---|---|---|
| July 30-Aug. 5 | 1,875 | 1,875 | 7.0 | 13 | 13 | 809 |
| Aug. 6-12 | 2,670 | 4,545 | 12.5 | 33 | 47* | 1,445 |
| Aug. 13-19 | 4,079 | 8,624 | 12.2 | 50 | 97* | 1,410 |
| Aug. 20-26 | 5,785 | 14,409 | 11.7 | 68 | 164* | 1,353 |
| Aug. 27-Sept. 1 | 5,968 | 20,377 | 9.8 | 59 | 223* | 1,133 |
| Sept. 2-8 | 5,655 | 26,032 | 9.1 | 51 | 274* | 1,052 |
| Sept. 9-20 | 6,705 | 32,737 | 10.7 | 72 | 346* | 1,237 |
| Sept. 21-28 | 6,840 | 39,577 | 9.0 | 61 | 408* | 1,041 |
| Sept. 29-Oct. 4 | 4,930 | 44,507 | 9.1 | 45 | 453* | 1,052 |
| Oct. 5-11 | 2,285 | 46,792 | 10.2 | 23 | 476 | 1,179 |
| Oct. 12-18 | 1,915 | 48,707 | 10.4 | 20 | 496 | 1,202 |
| Oct. 19-25 | 2,370 | 51,077 | 7.7 | 18 | 514 | 890 |
| Oct. 26-Nov. 1 | 2,155 | 53,232 | 9.6 | 21 | 535 | 1,110 |
| Nov. 2-8 | 1,800 | 55,032 | 9.3 | 17 | 552 | 1,075 |
| Nov. 9-20 | 1,265 | 56,297 | 7.4 | 9 | 561 | 856 |
| Nov. 21-27 | 590 | 56,887 | 13.4 | 8 | 569 | 1,549 |

$\bar{X}$ CPUE = 9.9 kg/trap haul

* cumulative catches used in Leslie analysis

Table 4. Catch and effort statistics for the snow crab fishery in Conception Bay (Area 16), Newfoundland, 1979.

| Two-Week period | Effort (trap hauls) | Cumulative effort | CPUE kg/trap haul | Catch M.T. | Cumulative catch M.T. | Estimated biomass (CPUE/q) M.T. |
|---|---|---|---|---|---|---|
| April 2-15 | 2,240 | 2,240 | 16.8 | 38 | 38 | 1,106 |
| April 16-29 | 6,910 | 9,150 | 18.9 | 130 | 168* | 1,244 |
| April 30-May 13 | 3,540 | 12,690 | 16.3 | 58 | 226* | 1,073 |
| May 14-27 | 4,800 | 17,490 | 14.6 | 70 | 296* | 961 |
| May 28-June 10 | 3,480 | 20,970 | 15.5 | 54 | 350* | 1,020 |
| June 11-24 | 2,555 | 23,525 | 16.1 | 41 | 391* | 1,060 |
| June 25-July 8 | 1,270 | 24,795 | 15.0 | 19 | 410* | 988 |
| July 9-22 | 1,840 | 26,635 | 13.4 | 25 | 435* | 882 |
| July 23-Aug. 5 | 1,250 | 27,885 | 13.0 | 16 | 451* | 856 |
| Aug. 6-19 | 780 | 28,665 | 14.0 | 11 | 462 | 922 |
| Aug. 20-Sept. 2 | 180 | 28,845 | 9.5 | 1.7 | 464 | 625 |

$\bar{X}$ CPUE = 16.1 kg/trap haul

* cumulative catches used in Leslie analysis

Table 5. Catch and effort statistics for the snow crab fishery in Northeastern Avalon (Area 18), Newfoundland, 1979.

| Two-Week period | Effort (Trap hauls) | Cumulative effort | CPUE kg/trap haul | Catch M.T. | Cumulative catch M.T. | Estimated biomass (CPUE/q) M.T. |
|---|---|---|---|---|---|---|
| April 2-15 | 4,420 | 4,420 | 21.5 | 95 | 95 | 11,891 |
| April 16-29 | 13,407 | 17,827 | 20.5 | 274 | 369 | 11,339 |
| April 30-May 13 | 24,545 | 42,372 | 19.0 | 467 | 836 | 10,509 |
| May 14-27 | 28,649 | 71,021 | 21.6 | 619 | 1455 | 11,947 |
| May 28-June 10 | 27,668 | 98,659 | 24.1 | 666 | 2121* | 13,330 |
| June 11-24 | 32,406 | 131,095 | 20.5 | 665 | 2786* | 11,339 |
| June 25-July 8 | 34,496 | 165,591 | 17.9 | 617 | 3403* | 9,900 |
| July 9-22 | 40,028 | 205,619 | 17.2 | 689 | 4091* | 9,513 |
| July 23-Aug. 5 | 34,578 | 240,197 | 17.7 | 613 | 4705* | 9,790 |
| Aug. 6-19 | 27,203 | 267,400 | 18.2 | 495 | 5199* | 10,066 |
| Aug. 20-Sept. 2 | 17,359 | 284,759 | 16.3 | 284 | 5483* | 9,016 |
| Sept. 3-16 | 12,807 | 297,566 | 14.7 | 189 | 5672* | 8,131 |
| Sept. 17-30 | 14,790 | 312,356 | 14.9 | 220 | 5891* | 8,241 |
| Oct. 1-14 | 11,580 | 323,936 | 16.0 | 185 | 6077* | 8,850 |
| Oct. 15-28 | 10,415 | 334,351 | 14.7 | 153 | 6230* | 8,131 |
| Oct. 29-Nov. 11 | 3,980 | 338,331 | 14.5 | 58 | 6288 | 8,020 |
| Nov. 12-25 | 3,692 | 342,023 | 14.9 | 55 | 6343 | 8,241 |
| Nov. 26-Dec. 9 | 2,040 | 344,063 | 12.6 | 26 | 6368 | 6,969 |
| Dec. 10-24 | 360 | 344,423 | 10.7 | 4 | 6372 | 5,918 |

$\bar{X}$ CPUE = 17.2 kg/trap haul

* cumulative catches used in Leslie analysis

Table 6. Catch and effort statistics for the snow crab fishery in Eastern Avalon (Area 14), Newfoundland, 1979.

| Two-Week period | Effort (trap hauls) | Cumulative effort | CPUE kg/trap haul | Catch M.T. | Cumulative catch M.T. | Estimated biomass (CPUE/q) M.T. |
|---|---|---|---|---|---|---|
| April 2-15 | 790 | 790 | 26.7 | 21 | 21 | 800 |
| April 16-29 | 2,030 | 2,820 | 22.6 | 46 | 67 | 678 |
| April 30-May 13 | 2,410 | 5,230 | 21.2 | 51 | 118 | 636 |
| May 14-27 | 3,370 | 8,600 | 22.4 | 76 | 194 | 672 |
| May 28-June 10 | 2,890 | 11,490 | 28.9 | 84 | 277* | 866 |
| June 11-24 | 2,990 | 14,480 | 26.6 | 79 | 357* | 797 |
| June 25-July 8 | 3,040 | 17,520 | 21.7 | 66 | 423* | 651 |
| July 9-22 | 3,190 | 20,710 | 16.6 | 53 | 475* | 498 |
| July 23-Aug. 5 | 3,240 | 23,950 | 16.0 | 52 | 527* | 480 |
| Aug. 6-19 | 3,640 | 27,590 | 18.6 | 68 | 595* | 558 |
| Aug. 20-Sept. 2 | 3,540 | 31,130 | 15.9 | 56 | 651* | 477 |
| Sept. 3-16 | 2,220 | 33,350 | 14.9 | 33 | 684* | 447 |
| Sept. 17-30 | 1,065 | 34,415 | 14.8 | 16 | 700 | 445 |
| Oct. 1-14 | 640 | 35,055 | 15.6 | 10 | 710 | 468 |
| Oct. 15-28 | 1,070 | 36,125 | 20.6 | 22 | 732 | 618 |
| Oct. 29-Nov. 11 | 935 | 37,060 | 17.7 | 17 | 749 | 531 |
| Nov. 12-25 | 890 | 37,950 | 15.4 | 14 | 762 | 462 |

$\bar{X}$ CPUE = 20.1 kg/trap haul

* cumulative catches used in Leslie analysis

Table 7. Catch and effort statistics for the snow crab fishery in White Bay (Area 36), Newfoundland, 1979.

| Two-Week period | Effort (trap hauls) | Cumulative effort | CPUE kg/trap haul | Catch M.T. | Cumulative catch M.T. | Estimated biomass (CPUE/q) M.T. |
|---|---|---|---|---|---|---|
| June 11-24 | 1,168 | 1,168 | 9.6 | 11 | 11* | 386 |
| June 25-July 8 | 1,608 | 2,776 | 9.5 | 15 | 26* | 382 |
| July 9-22 | 3,340 | 6,116 | 7.3 | 24 | 51* | 294 |
| July 23-Aug. 5 | 3,534 | 9,650 | 6.4 | 23 | 74* | 257 |
| Aug. 6-19 | 3,697 | 13,347 | 8.0 | 30 | 103* | 322 |
| Aug. 20-Sept. 2 | 2,011 | 15,358 | 7.0 | 14 | 117* | 282 |
| Sept. 3-16 | 2,593 | 17,951 | 6.1 | 16 | 133* | 245 |
| Sept. 17-30 | 789 | 18,740 | 8.0 | 6 | 139 | 322 |
| Oct. 1-14 | 1,554 | 20,294 | 5.7 | 9 | 148* | 229 |
| Oct. 15-28 | 887 | 21,181 | 7.4 | 7 | 155 | 298 |
| Oct. 29-Nov. 11 | 117 | 21,298 | 11.8 | 1.4 | 156 | 475 |

$\bar{X}$ CPUE = 7.3 kg/trap haul

* cumulative catches used in Leslie analysis

Table 8. Catch and effort statistics for the snow crab fishery in Green Bay (Area 32), Newfoundland, 1979.

| Two-Week period | Effort (trap hauls) | Cumulative effort | CPUE kg/trap haul | Catch M.T. | Cumulative catch M.T. | Estimated biomass (CPUE/q) M.T. |
|---|---|---|---|---|---|---|
| June 4-17 | 2,480 | 2,480 | 15.6 | 39 | 39* | 853 |
| June 18-July 1 | 2,242 | 4,722 | 15.6 | 35 | 74* | 853 |
| July 2-15 | 3,188 | 7,910 | 15.5 | 49 | 123* | 848 |
| July 16-29 | 3,465 | 11,375 | 12.8 | 44 | 167* | 700 |
| July 30-Aug. 12 | 4,585 | 15,960 | 10.3 | 47 | 214* | 563 |
| Aug. 13-26 | 4,329 | 20,289 | 11.1 | 48 | 262* | 607 |
| Aug. 27-Sept. 9 | 3,155 | 23,444 | 9.5 | 30 | 292* | 519 |
| Sept. 10-23 | 3,930 | 27,374 | 9.7 | 38 | 330* | 530 |
| Sept. 24-Oct. 1 | 4,125 | 31,499 | 9.0 | 31 | 367* | 492 |
| Oct. 8-21 | 5,515 | 37,014 | 8.2 | 45 | 413* | 448 |
| Oct. 22-Nov. 5 | 4,712 | 41,726 | 9.5 | 45 | 458* | 519 |
| Nov. 6-19 | 2,734 | 44,460 | 8.0 | 22 | 479* | 437 |
| Nov. 20-Dec. 2 | 1,723 | 46,183 | 7.1 | 12 | 491* | 388 |

$\bar{X}$ CPUE = 10.6 kg/trap haul

* cumulative catches used in Leslie analysis

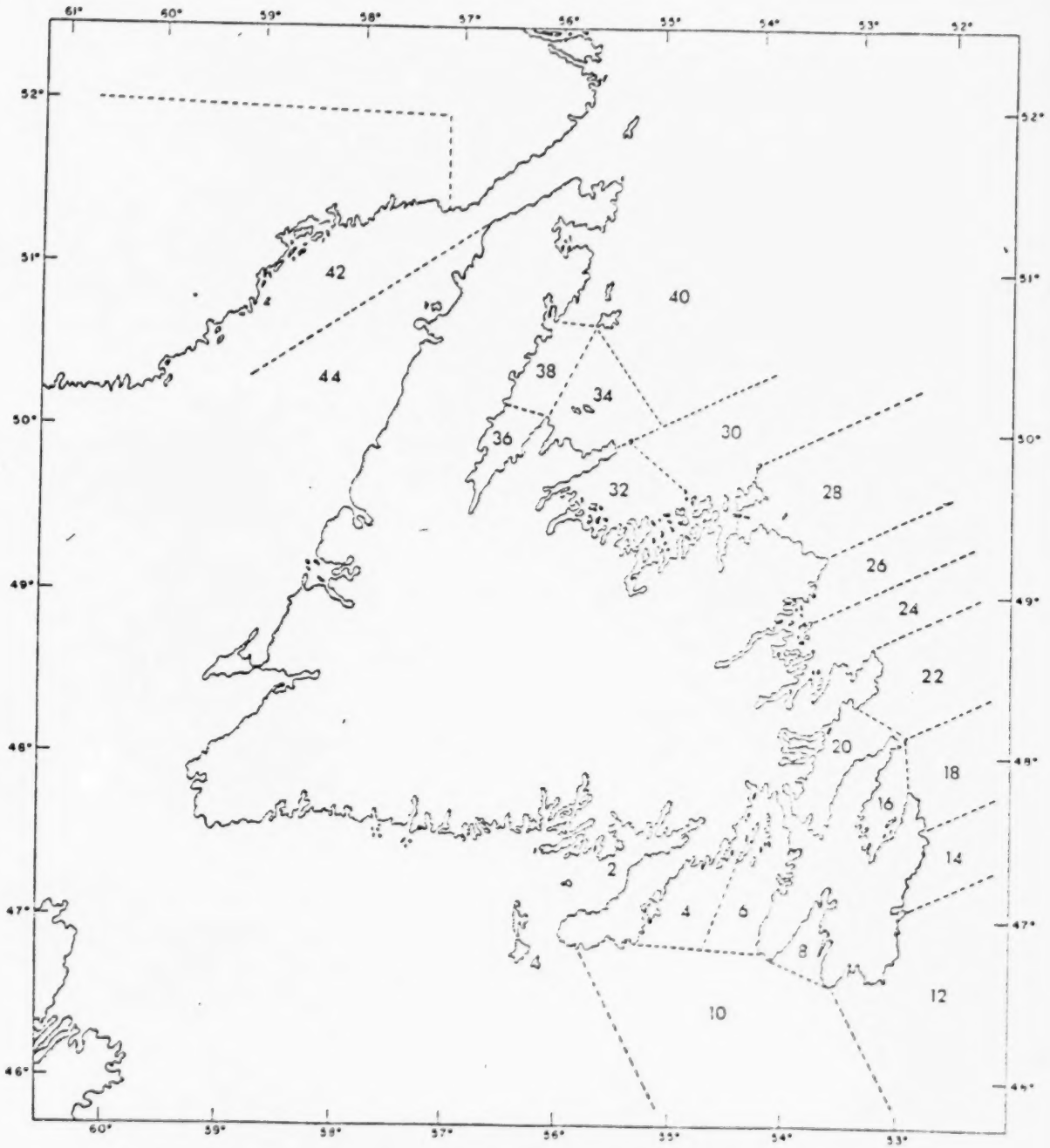


Fig. 1. Snow crab management areas (after Miller).

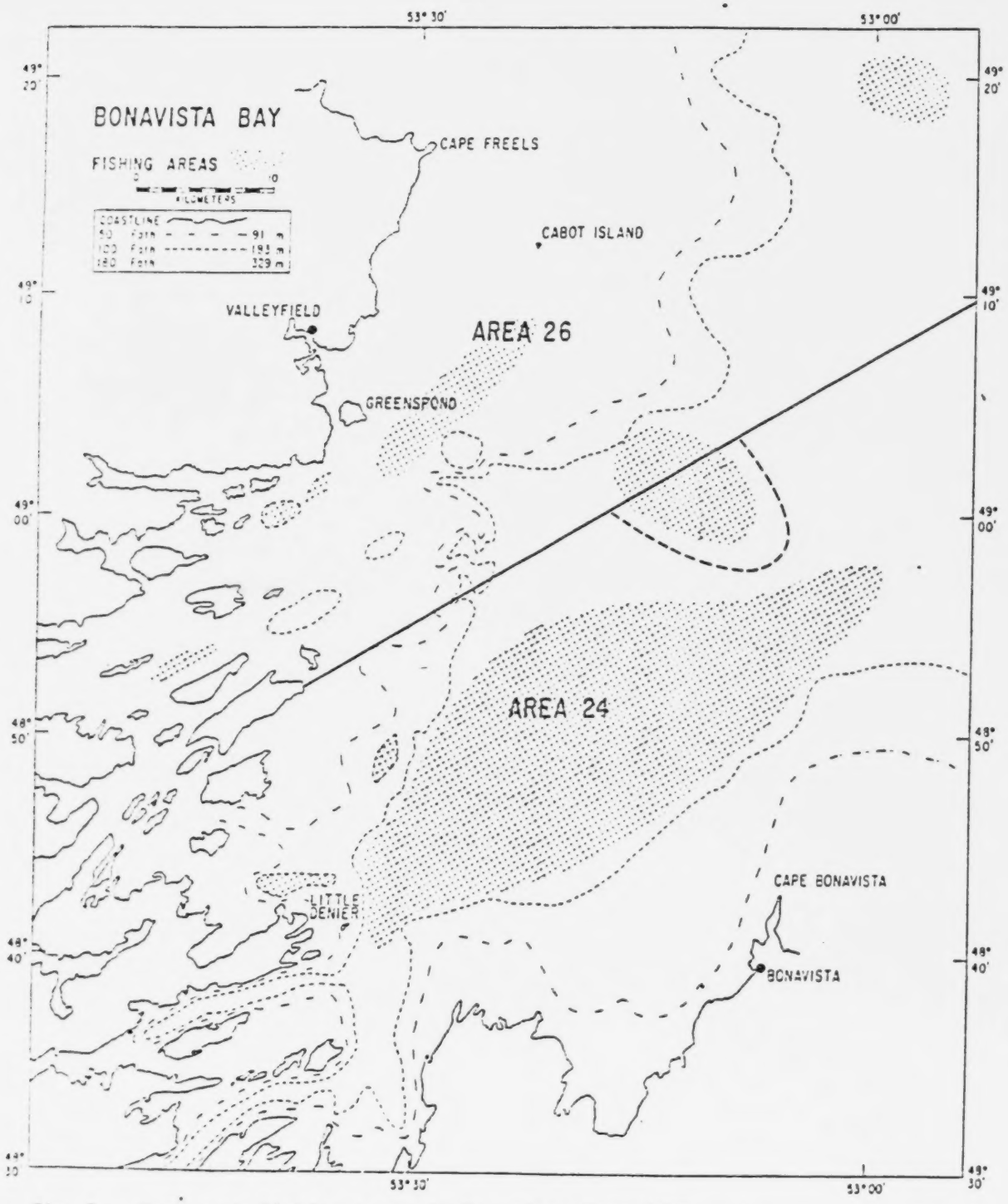


Fig. 2. Snow crab fishing areas in Bonavista Bay, 1979.

Note: Dashed line indicates a portion of Area 24 which should be included in Area 26.

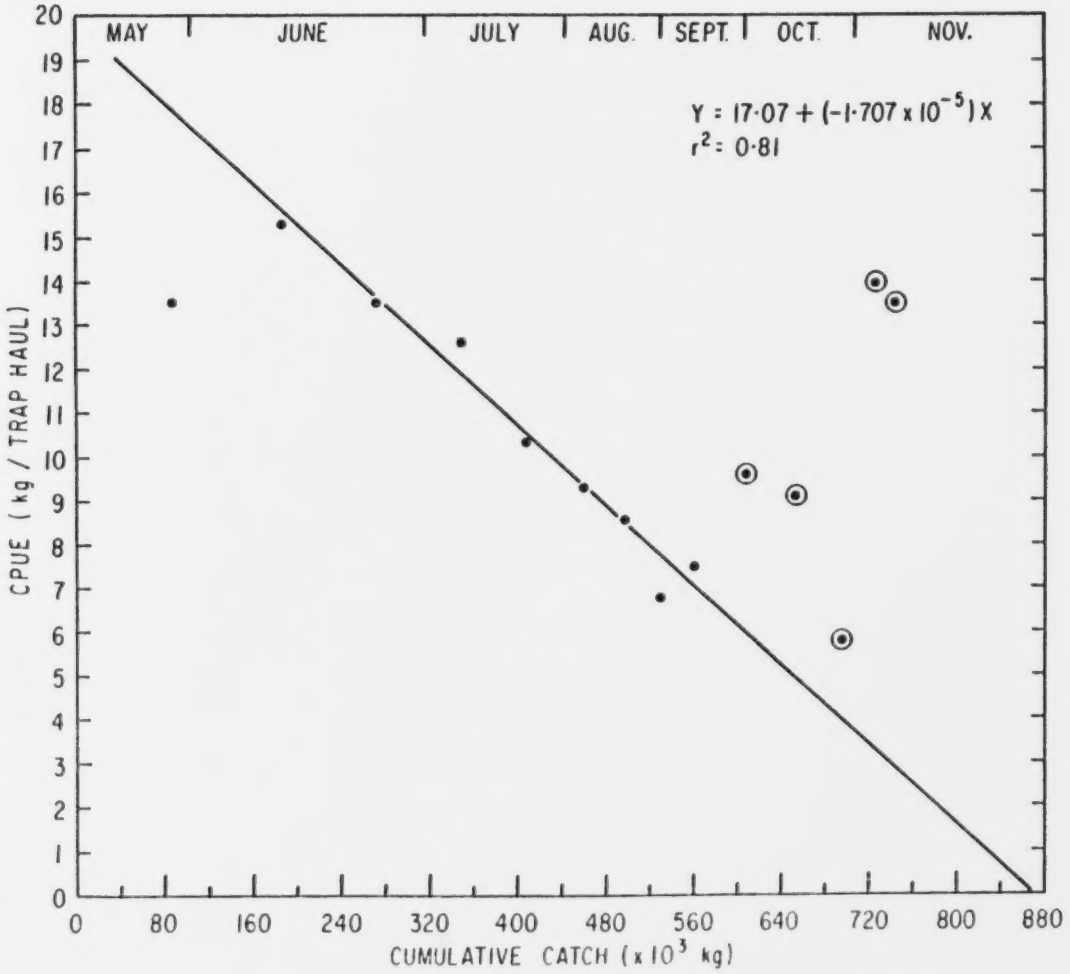


Fig. 3. Leslie graph of bi-weekly catches of snow crab from the western side (area 26) of Bonavista Bay, Newfoundland, 1979.

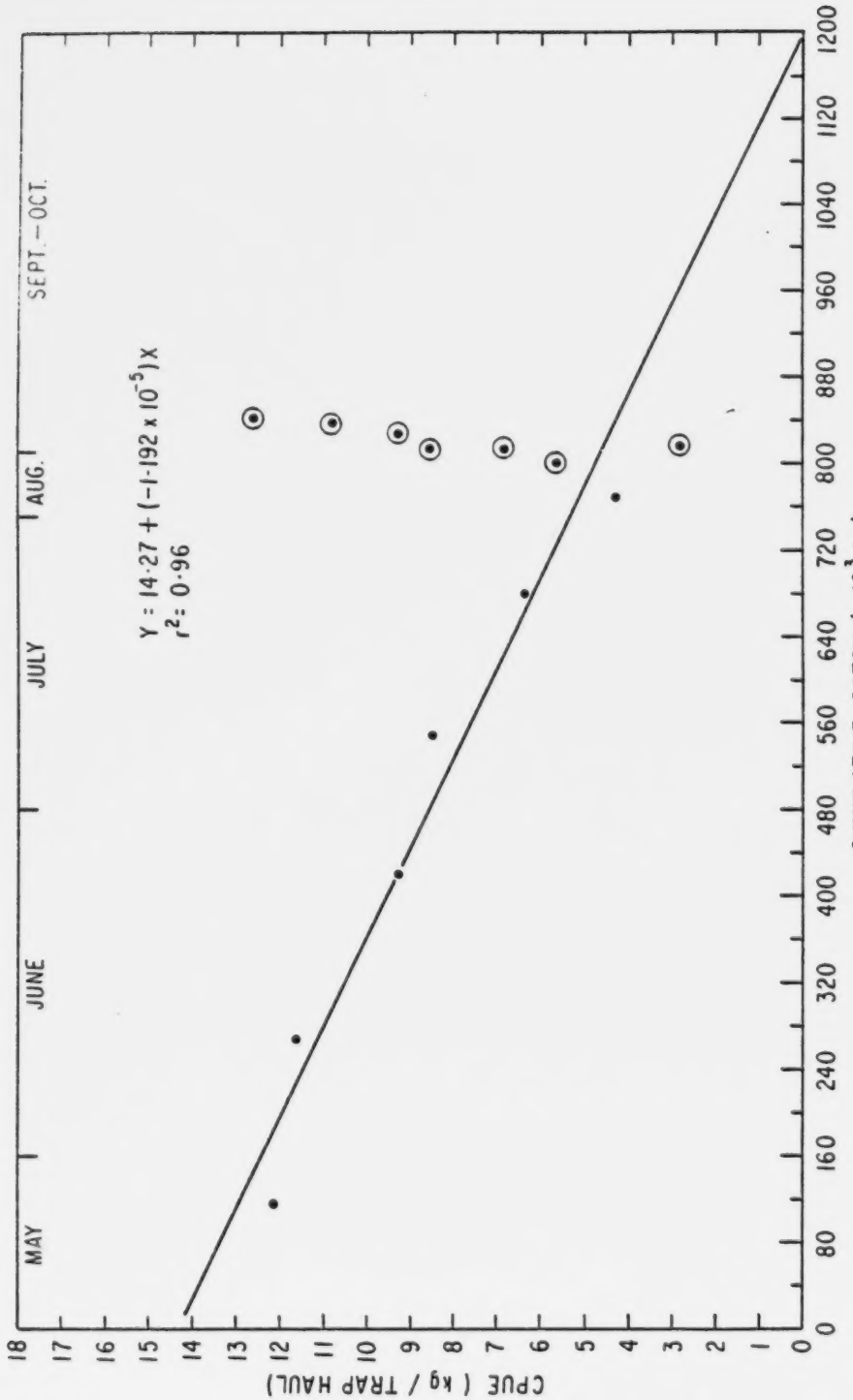


Fig. 4. Leslie graph of bi-weekly catches of snow crab from the eastern side (area 24) of Bonavista Bay, Newfoundland, 1979.

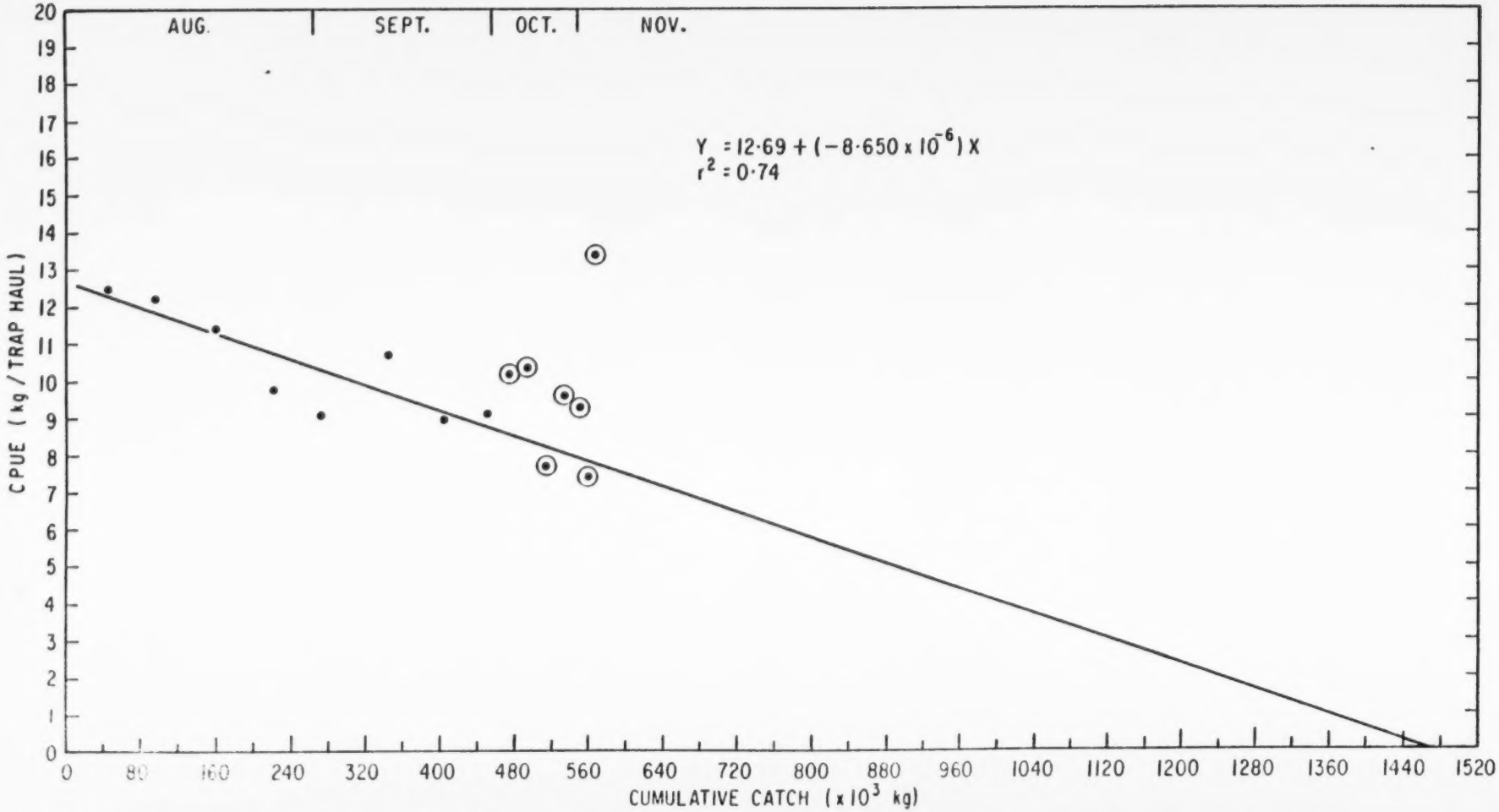


Fig. 5. Leslie graph of weekly catches of snow crab from Trinity Bay (area 22), Newfoundland, 1979.

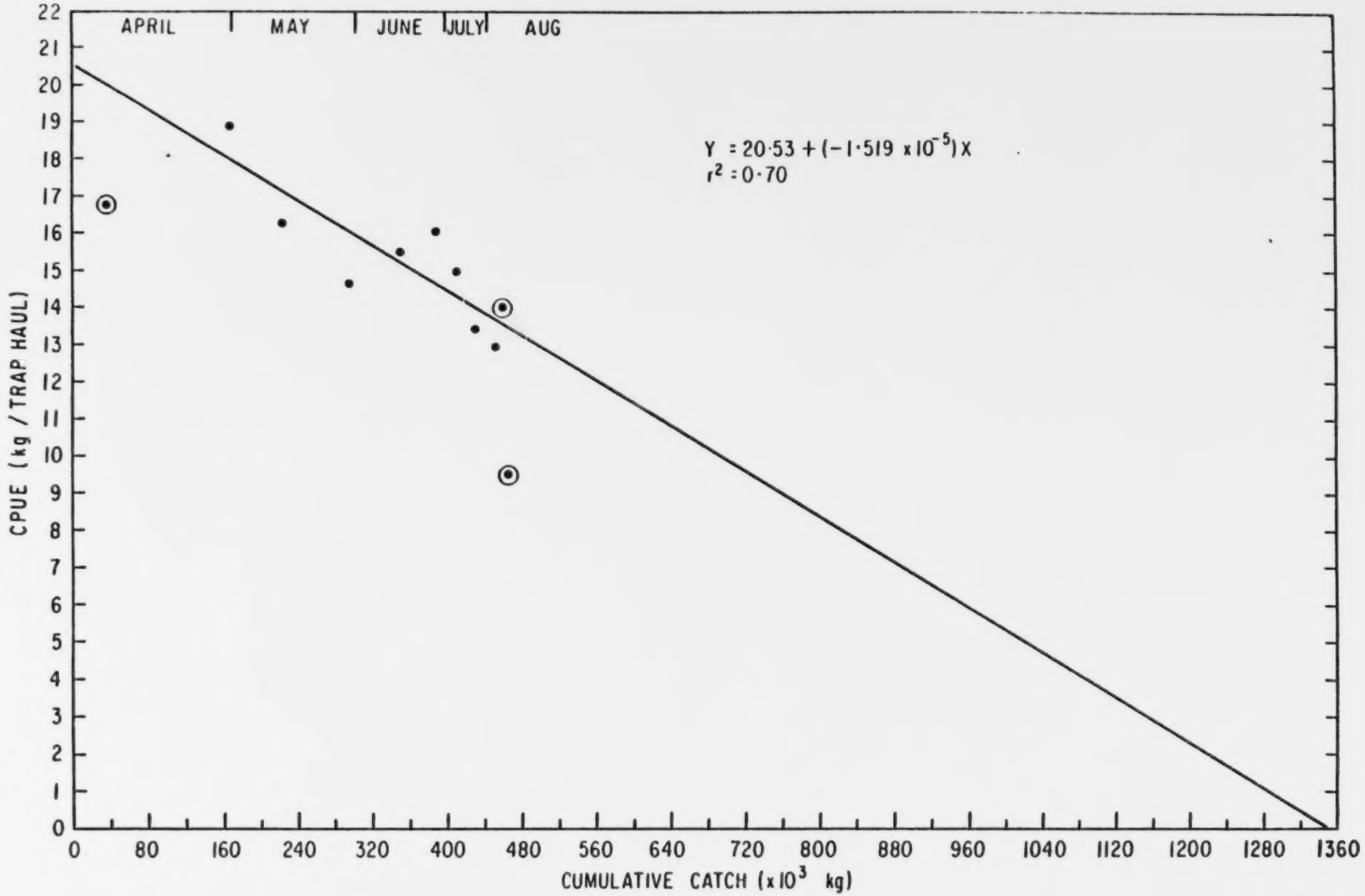


Fig. 6. Leslie graph of bi-weekly catches of snow crab from Conception Bay (area 16), Newfoundland, 1979.

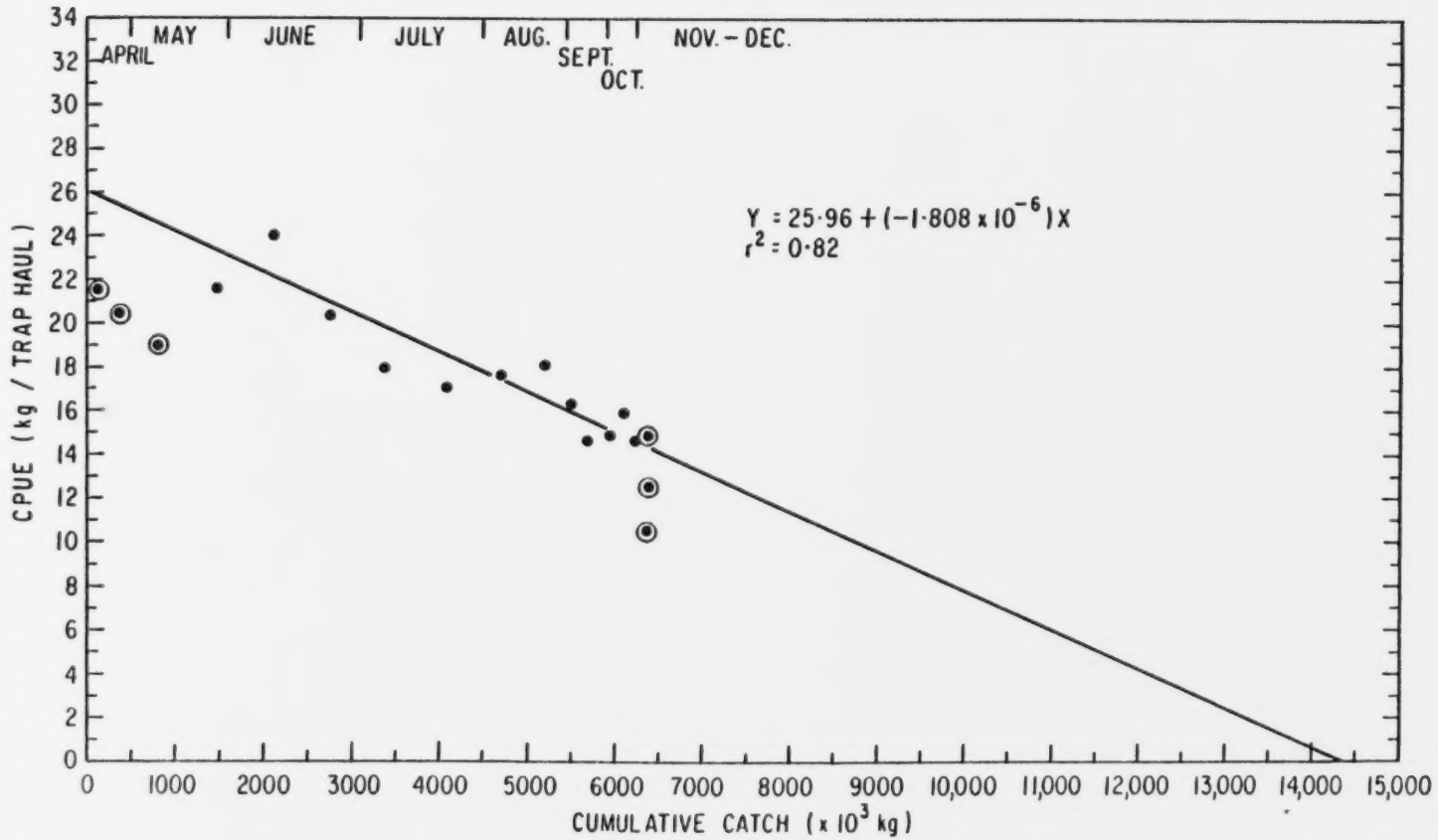


Fig. 7. Leslie graph of bi-weekly catches of snow crab from northeastern Avalon (area 18), Newfoundland, 1979.

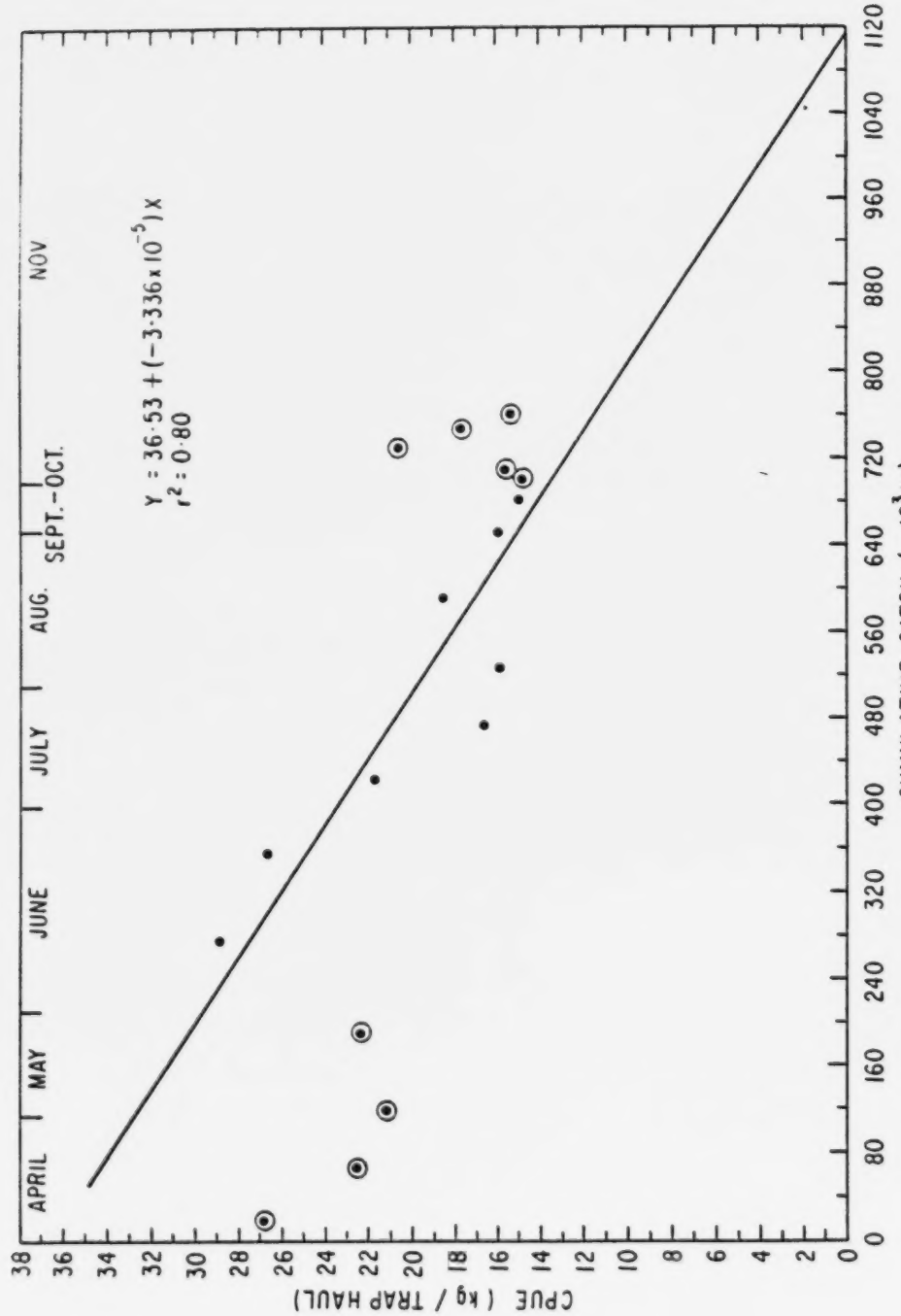


Fig. 8. Leslie graph of bi-weekly catches of snow crab from eastern Avalon (area 14), Newfoundland, 1979.

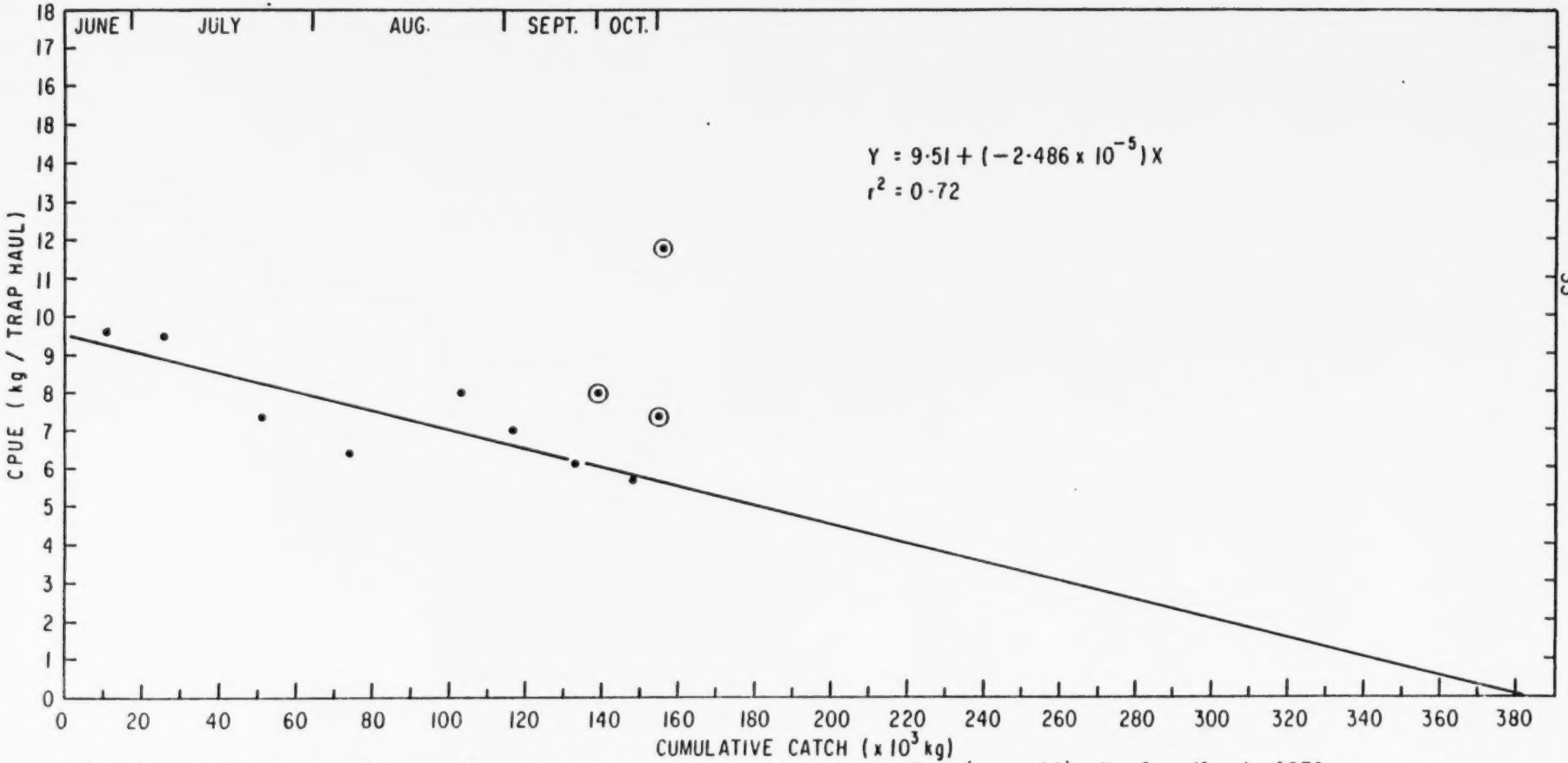


Fig. 9. Leslie graph of bi-weekly catches of snow crab from White Bay (area 36), Newfoundland, 1979.

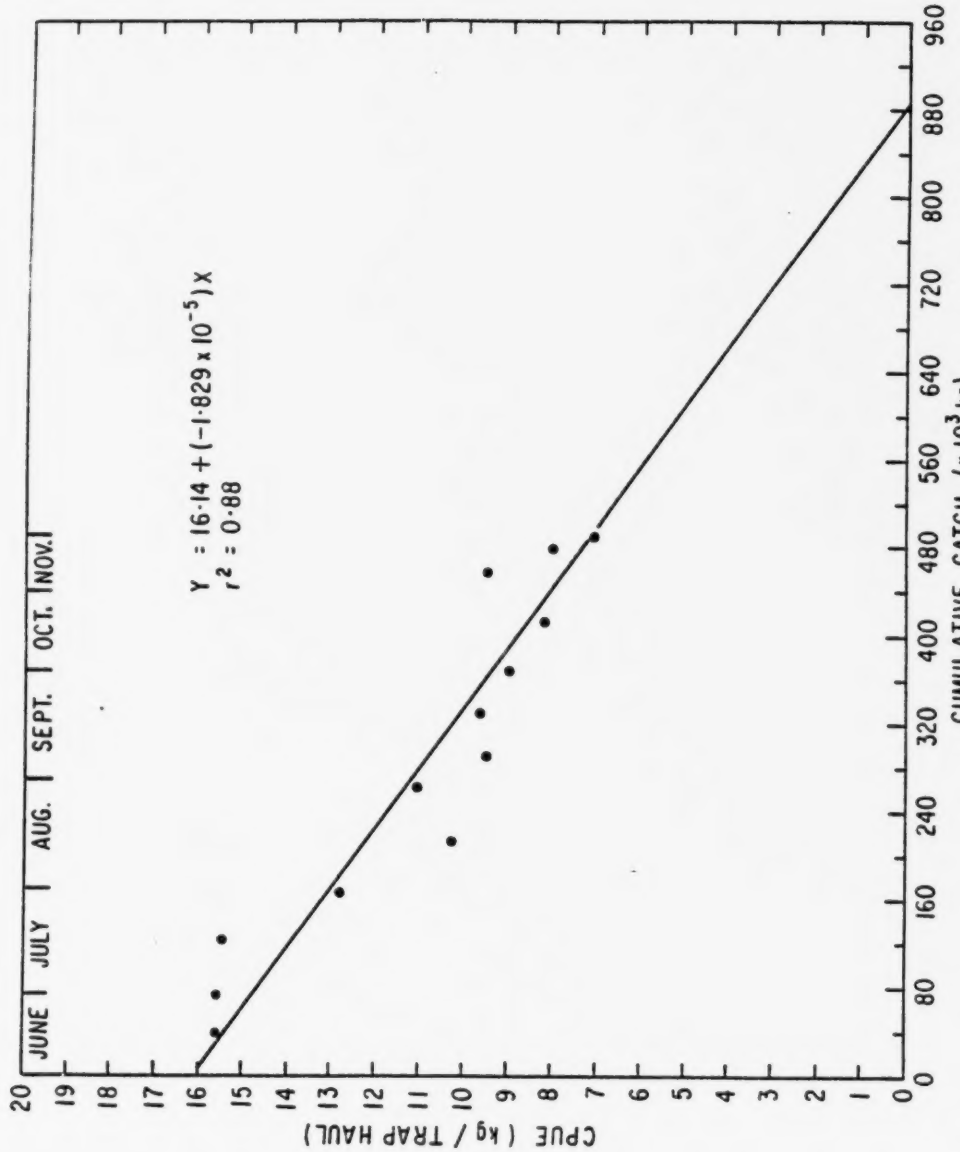


Fig. 10. Leslie graph of bi-weekly catches of snow crab from Green Bay (area 22), Newfoundland, 1979.